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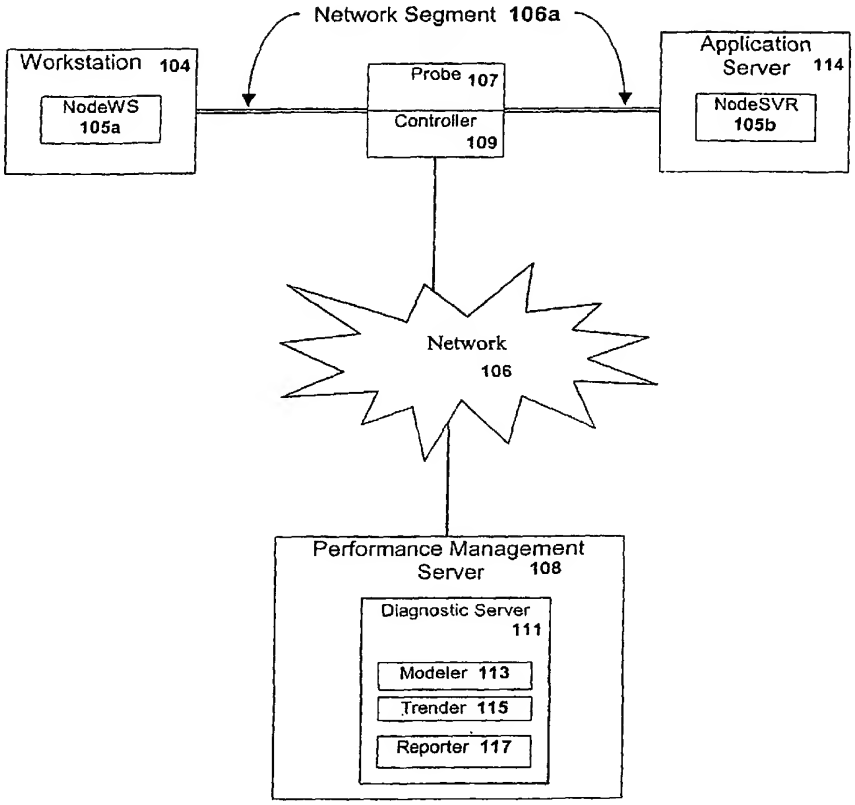
(54) Title: SYSTEMS AND METHODS FOR END-TO-END QUALITY OF SERVICE MEASUREMENTS IN A DISTRIBUTED NETWORK ENVIRONMENT



(57) Abstract: The present invention provides a framework for metering, monitoring, measuring, analyzing and reporting on network traffic data. In certain configurations, the present invention includes two metering/measuring components, the first being referred as Node Workstation and Node Server and the second being referred to as Probe. The Probe monitors all traffic that traverses the network segment upon which it is installed, while Node is limited to the traffic specific to the particular host. The metering/measuring components communicate their data to monitoring, analysis, and reporting software modules that rely upon and reside in another component referred to as Diagnostic Server. The Diagnostic Server may accept data from the metering/measuring components and stores such data for use by software modules that perform the monitoring, trending, capacity planning and reporting functions.

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SYSTEMS AND METHODS FOR END-TO-END QUALITY OF SERVICE MEASUREMENTS IN A DISTRIB UTED NETWORK ENVIRONMENT

Technical Field

for metering and measuring the performance of a distributed network. More particularly, the present invention relates to systems and methods for providing end-to-end quality of service measurements in a distributed network environment.

Background of the Invention

[002] The OSI model does not define any specific protocols, but rather the functions that are carried out in each layer. It is assumed that these functions are implemented as one or more formalized protocols as applicable to the particular data communication system being implemented. As a concrete example, the TCP/IP protocol model is conceptually simpler than the OSI model. It consists of just four layers (network access, internet, transport, application). The network access layer corresponds to the OSI physical and data link layers, and is defined in terms of physical networks such as Ethernet, Token Ring, ATM, etc. The Internet layer corresponds to the OSI network layer and includes protocols such as IP, ICMP, and IGMP. The transport layer is essentially the same in both models, and includes TCP and UDP. The application layer is broadly defined and includes functionality from the OSI session, presentation, and application layers. Protocols at this level include SMTP, FTP, and HTTP.

[003] While traditional network monitors may classify and present information about application traffic, they are not really monitoring the applications themselves. They are instead providing stateless information about the protocols used by the applications and ignore higher-level information, such as session metrics. For example, they may report that workstation 10.0.0.1 was the source of 1000 FTP packets, but do not break down individual file transfers for throughput analysis. Such a breakdown requires state information, that is, knowing when an application initiates a transaction and when the transaction is completed.

[004] The primary metric for application quality of service, at least for transaction-oriented applications, is application response-time or responsiveness. Therefore, any device configured to monitor application quality of service must be able to identify complete transactions or conversations. Some exceptions to this include streaming applications, such as Voice over IP (VoIP), for which the primary metric(s) change to throughput and jitter (packet inter-arrival variation), but the need to discern state information, such as per-call statistics, still exists.

[005] Accordingly, a system is needed that combines data capture and analysis so as to provide real-time and continuous monitoring of end-to-end application quality of service, rather than snapshot, periodic and/or batch-oriented reporting.

Summary of the Invention

[006] The present invention provides a framework for metering, monitoring, measuring, analyzing and reporting on network traffic data. The framework of the present invention is comprised of multiple synchronized components that each contribute highly specialized functionality (intelligence) to the framework as a whole. The component structure of the present invention provides flexibility that makes the framework scalable and robust. The framework of the present invention may be tailored to fit specific objectives, needs and operating processes. This tailored flexibility can dramatically lower the costs and effort expended on on-going technology management and customer support by allowing the framework to conform to an entity's support process rather than forcing entities to change their operating processes to match the tool.

[007] The present invention also lowers the technical cost of managing infrastructures in terms of resource overhead and data warehousing by providing intelligent

routing/filtering of collected information. By intelligently parsing captured data, information can be discretely grouped and delivered to vertically oriented resources and indeed specific individuals. This enables the benefit of just in time (JIT) information delivery, eliminating the need for batch/bulk uploads to massive back-end data repositories and the capital expenditure associated with abortive sorting and parsing systems.

[008] In certain configurations, the present invention includes two types of metering/measuring components, referred to as Instrumentation Access Points (IAPs). The first metering/measuring component is a terminal IAP, referred to as NodeWS (Node Workstation) and NodeSVR (Node Server). NodeWS and NodeSVR are interchangeably referred to herein as Node(s). The second metering/measuring component is an edge IAP, referred to as Probe. Probe monitors all traffic that traverses the network segment upon which it is installed, while Node is limited to the traffic specific to the particular host (i.e., workstation or server).

[009] The IAPs communicate their data to monitoring, analysis, and reporting software modules that rely upon and reside in another component referred to as Diagnostic Server. Diagnostic Server may be configured in two orientations, including a "Domain" version for supporting small to medium businesses or localized domain management and an "Enterprise" version for supporting large scale service providers and enterprise corporations. Each version of Diagnostic Server may accept data from the IAP and stores such data for use by software modules referred to as: Modeler, Trender and Reporter. These three software modules perform the monitoring, trending, capacity planning and reporting functions of the present invention.

[010] Additional embodiments, examples, variations and modifications are also disclosed herein.

Brief Description of the Drawings

[011] FIG. 1 is a high-level block diagram illustrating the components that make-up the framework of the present invention according to one or more exemplary embodiments thereof.

Detailed Description of Exemplary Embodiments

[012] The present invention provides a flexible, scalable and robust system for providing end-to-end quality of service measurements in a distributed network environment. Exemplary embodiments of the present invention will now be described with reference to FIG. 1, which represents a high-level block diagram of a system in accordance with certain exemplary embodiments. As depicted, an exemplary operating environment includes various network devices configured for accessing and reading associated computer-readable media having stored thereon data and/or computer-executable instructions for implementing various methods of the present invention. The network devices are interconnected via a distributed network **106** comprising one or more network segments **106a**. The network **106** may be composed of any telecommunication and/or data network, whether public or private, such as a local area network, a wide area network, an intranet, an internet and any combination thereof and may be wire-line and/or wireless.

[013] Generally, a network device includes a communication device for transmitting and receiving data and/or computer-executable instructions over the network **106** and a memory for storing data and/or computer-executable instructions. A network device may also include a processor for processing data and executing computer-executable instructions, as well as other internal and peripheral components that are well known in the art (e.g., input and output devices.) As used herein, the term "computer-readable medium" describes any form of computer memory or a propagated signal transmission medium. Propagated signals representing data and computer-executable instructions are transferred between network devices.

[014] A network device may generally comprise any device that is capable of communicating with the resources of the network **106**. A network device may comprise, for example, a server (e.g., Performance Management Server **108** and application server **114**), a workstation **104**, and other devices. In the embodiment shown in FIG. 1, a Performance Management Server **108** hosts software modules for communicating with other network devices and for performing monitoring, trending, capacity planning and reporting functions. The Performance Management Server **108** is a specially configured component of the present invention. In contrast, the application server **114** is meant to generically represent any other network server that may be connected to the network **106**. The term "server"

generally refers to a computer system that serves as a repository of data and programs shared by users in a network **106**. The term may refer to both the hardware and software or just the software that performs the server service.

[015] A workstation **104** may comprise a desktop computer, a laptop computer and the like. A workstation **104** may also be wireless and may comprise, for example, a personal digital assistant (PDA), a digital and/or cellular telephone or pager, a handheld computer, or any other mobile device. These and other types of workstations **104** will be apparent to one of ordinary skill in the art.

[016] Certain embodiments may include various metering/monitoring components, also referred to as instrument access points ("IAPs"), such as NodeWS (Node Workstation) **105a**, NodeSVR (Node Server) **105b** and Probe **107**. NodeWS **105a** and NodeSVR **105b** are terminal IAP and may be referred to collectively as Node **105**. Probe **107** is an edge IAP. In a sense, Probe **107** and Node **105** are application aware network monitors. Traditional network monitors, commonly called sniffers, use a passive network interface to identify and measure network traffic at the packet or cell level. Sniffers provide information about the lower four layers in the OSI network model (physical, data link, network, and transport), but largely or entirely ignore the upper three levels (session, presentation, application). Probe **107** and Node **105**, on the other hand, are configured to provide information about all seven layers in the OSI network model.

[017] The concept of measuring traffic flows, or conversations, is essentially the same for both Node **105** and Probe **107**. A stream of network packets is presented to the metering/monitoring component. The component may be configured to classify the network packets into traffic flows, summarize attributes of the traffic flows and store the results for subsequent reporting and possible transfer to another component of the invention. The stream of network packets is pre-filtered to a particular host in the case of Node **105**.

[018] Node **105** is a software agent designed to attach to the protocol stack in workstations **104** and application servers **114**. Node **105** performs traffic metering for the traffic that is sent to or from its host. In addition, Node **105** monitors the overall status of the host for KPIs (Key Performance Indicators) that might affect application responsiveness, such as CPU and memory utilization, streaming, current user login information, etc. While

it is a straightforward task to obtain localized user login information at a workstation **104** where the mapping is generally one-to-one, multiple user logins must be correlated to multiple applications at the server end. Correlating multiple user logins to multiple applications provides views into resource allocation, performance and utilization characteristics at the process level. Apart from the obvious network interface, there are several other interfaces between Node **105** and other subsystems within the framework. In addition, there are user interfaces.

[019] Probe **107** is a dedicated network traffic monitoring appliance that, through promiscuous network interface(s), continuously and in real-time classifies packets into traffic flows as described above. In terms of traffic classification, reporting, and diagnostic support, Probe **107** is virtually identical to Node **105** except that it sees all network traffic on the network segment **106a**. Probe **107** may also include a direct user interface that provides "live" analysis of traffic data. Various views provide an analyst with information that may help diagnose problems immediately; whereas waiting for summarized data and reports may make it difficult to solve the problem in a timely fashion. In addition to the obvious network interface, there are several other interfaces between Probe **107** and other subsystems within the framework. In addition, there are user interfaces.

[020] While Probe **107** is capable of providing packet analysis, it is designed to produce statistical information characterizing the application and network quality of service. Probe **107** also provides important information about application QoS through its graphical user interface. Since it is collecting transport and network information already, as required to measure application performance, Probe **107** may serve as a stand-alone device to provide functionality similar to traditional network monitors (i.e., packet-trace analysis).

[021] Most good network analyzers can filter or present data by criteria, such as: source IP address, destination IP address, source Port, destination Port, and/or protocols (e.g., Ethernet, IP, ICMP, TCP, UDP, Telnet, FTP, HTTP). More sophisticated analyzers will make some attempts at decoding portions of the protocol attributes; others will simply present the data in text (ASCII) or numeric (hexadecimal) format. Probe **107** supports all of this and also interprets the data at the application level.

[022] Probe **107** may be provided with a graphical user interface that allows an analyst or administrator to view live information about the traffic seen by Probe **107**. Through this user interface, users can obtain chart and/or graphical representations of system metrics through different views. The traffic can be filtered, summarized, categorized and presented based on user selection criteria, much the same as traditional network analyzers present data. Application specific metrics must also be filtered, summarized, categorized and presented based on user criteria.

[023] The user interface can be presented locally or remote with equal facility. Indeed, as a network appliance, Probe's **107** user interface may always be accessed remotely (much like routers and firewalls are often accessed). This eliminates the need for loading Probe **107** with a keyboard, mouse, and video display. In addition to a remote graphical user interface, Probe **107** may be configured for interacting with remote applications that depend on SNMP or RMON protocols to transport information to remote analysis tools, both within the framework of the present invention and with custom and/or third-party tools.

[024] Node **105** and Probe **107** each summarize (or aggregate) the information that they collect and communicate the aggregate information to a Controller **109**. According to certain embodiments of the invention, a Controller **109** is assumed to be within each "Domain." A Domain is defined herein as a localized area of integrated Probes **107** and instrumented Nodes **105**. Each Controller is responsible for managing all Probes **107** and Nodes **105** within its Domain. Each Controller **109** holds a database of Service Level criteria, and can use the aggregate data received from Node **105** and/or Probe **107** to valid the performance of each application, for each user, in terms of the required service levels that directly affect that user. Defined routing and filtering of Domain-oriented information can then be directed to specific repositories and indeed specific support personnel.

[025] The aggregate data described above is sufficient to document or validate Service Level compliance. It is not, however, sufficient to pinpoint why required levels of service are not being met. While inferences can be made from the aggregate data, especially when similar aggregate data from several points between two nodes (workstation **104** and application server **114**) are compared and correlated, there are conditions that require more information. In particular support personnel will need to be able to track a particular set of

packets on their trip through the network **106**, noting the time they passed each point in the network **106**.

[026] Node **105** and Probe **107** each support these diagnostic requirements by providing a mode (on demand, presumably in response to some alarm indicating service level breach) that allows selective accumulation of per-conversation data (rather than aggregating many conversations during an interval). The per-conversation data, with its time tags and identifying data, is reported to Controller **109**, and eventually to Diagnostic Server **111**, where data from different instrumentation points can be correlated into a comprehensive picture of the entire application performance including network, workstation **104**, and application server **114** information. The collection of per-conversation information can require more memory consumption in the workstation **104**, as well as more network bandwidth. This is the price that must be paid when this diagnostic mode is required. However, the diagnostic mode may be invoked when the requirement is demanded and turned-off when not appropriate.

[027] Controller **109** is the primary repository for Service Level definitions and provides a data service to Node **105** and Probe **107**. Node **105** and Probe **107** receive Service Level-related information from Controller **109**, including service level requirements and thresholds, applications to be monitored, measurement intervals and where and to whom data should be sent. This information is used to limit the applications or protocols that Node **105** and Probe **107** need to report. Node **105** and Probe **107** provide a data stream service to Controller **109**. That data stream consists of periodic (user-defined frequency) transfers of aggregate interval data.

[028] Controller may also emit commands to Node **105** and/or Probe **107** asynchronously. These commands might reflect updated Service Level (filter) data, or might request that Node **105** and/or Probe **107** begin providing diagnostic-level data (i.e., per-conversation data) rather than normal aggregate data.

[029] Node **105** and Probe **107** use a discovery protocol to locate the Controller **109** that "owns" that node. This avoids requiring any configuration information to be retained within the Node **105** or Probe **107**. Node **105** also informs Controller **109** about its host address (IP & MAC), as well as the login information of the user. This permits

Controller **109** to map traffic data to a user and users to SLAs. Accordingly, service level and QoS metrics can be applied to transactions generated by the exact users to which quality expectations and guarantees apply. This process occurs within Controller **109** instead of the back-end processing currently offered by other solutions to facilitate immediate notification of non-compliance situations.

[030] Controller **109** receives collected data from Probes **107** and Nodes **105** at specified time intervals. Once the data arrives at Controller **109**, it is analyzed and transported to Diagnostic Server **111** where it is then utilized by Modeler **113**, Predictor **115**, and Reporter **117**. The diagnostic capabilities of Controller **109** complement those of Node **105** and Probe **107**. When Controller **109** indicates a certain service level or quality of service threshold is being breached, it invokes on-demand per-conversation reporting by the applicable Probes **107** and Nodes **105**. Controller **109** receives this per-conversation information, analyzes it and sends it to Diagnostic Server **111** for further processing and reporting. When it is determined that the non-compliance situation has ended, Controller **109** sends an instruction to Probe **107** and Node **105** that causes them to revert to normal "all-clear" reporting mode, in which summary traffic data is collected. Controller **109** may be provided with a graphical user interface so that applicable service levels, application identification information and measurement criteria can be entered and subsequently transmitted to Probe **107** and Node **105**.

[031] Packet capture is the act of observing all network traffic. Node **105** observes all traffic into and out of the host (e.g., workstation **104** or application server **114**) it is running on, while Probe **107** observes all traffic on the network segment **106a**. Packet capture may be accomplished with select network interface cards ("NIC") by commanding them to enter *promiscuous* mode. Normally, a NIC on a shared-media network, such as Ethernet, uses hardware-based filtering to ignore all packets not addressed, at the link layer (MAC address), to that particular NIC. Promiscuous mode disables the MAC address filtering and allows the NIC to see all packets regardless of the designated recipient.

[032] Observation of all network traffic may result in what appears to be a significant amount of data. But, consider that a fully loaded, collision-free 100baseT Ethernet network carries only 12.5 megabytes of data per second. In packet terms, this is slightly more than 195,312 minimum-sized packets per second, or about one packet every

5.12 microseconds. Actual capacity will likely be somewhat less due to signaling overheads (the preamble, which allows start-of-packet synchronization, is the equivalent of 8 bytes per packet) and collisions that reduce effective capacity even more. In fact, when assuming minimum packet size, signaling overhead and packet checksums represent nearly 17% of the bandwidth. Also note that the preamble and CRC are not usually available to upper layers of the protocol stack, so the actual amount of effective bandwidth is that much smaller. Adding some perspective, a 700MHz processor that executes one instruction per clock would be able to execute more than 3500 instructions per packet in this worst-case scenario. In any case, whether in Node **105** or Probe **107**, a packet capture mechanism may be postulated that produces a stream of packets. The packet stream can be fed into the next step of the traffic flow metering process, which is traffic classification.

[033] Once the packets are captured by Node **105** and Probe **107**, they must be classified, or put into specific categories so that they can be properly processed. The first step in classifying packets is to parse them. Parsing is the act of identifying individual fields in the packet. Most protocol headers have a fixed header, which tells us how to interpret the variable portion of the packet (the payload). After the packets are parsed, the information in each field can be used to classify the type of packet in terms of sender, receiver, protocol, application, etc. Once classified, a set of operations appropriate to the packet's categories can be invoked. For example, we can identify all packets involved in a particular session, then compute session statistics.

[034] Each layer in the protocol stack (TCP/IP over Ethernet will be assumed herein by way of example only) encapsulates data from the next-highest layer, usually adding header and/or trailer information. For example, consider the example where an FTP client asks TCP to transmit some data to an FTP server, having previously established a TCP session with the FTP server application. TCP will take the data from the application, break it up into properly sized chunks, and add a TCP header to each segment (the TCP header is generally 20 bytes that include source and destination ports, sequence and acknowledgment numbers, etc.). TCP will then ask IP to send the segments to the FTP server machine. IP will break the segments into properly sized chunks and construct one or more IP datagrams, each with an IP header (the Ipv4 header is generally 20 bytes that include source and destination IP address, header and data lengths, protocol an type-of-service identifiers, and fragmentation data). IP will then ask the network layer (e.g.,

Ethernet) to transmit them. Ethernet constructs an Ethernet frame, each with an Ethernet header (6-byte source and destination MAC addresses, and two more bytes with additional information), which is then transmitted onto the carrier media. Note that the transceiver hardware generates the preamble bits and a 4-byte trailing CRC.

[035] Parsing an Ethernet packet involves, at a minimum, breaking out the headers of each encapsulating protocol layer. The information in each layer's header indicates how to break up the header fields (some layers have variable-length headers), and usually indicate something about the next protocol layer. For example, the IP header will indicate whether the datagram is transporting TCP, UDP, RTP, or RSVP. This allows the transport layer protocol to be identified as, e.g., TCP for appropriate parsing.

[036] Finally, although TCP/IP does not specifically identify the concept, most applications will embed a session protocol in their datastreams. For example, the FTP application layer defines a score of commands (e.g., USER, PASS, and CWD) that the application may use. These commands are not included in a header, per se, instead appearing as bytes in the FTP data stream. As application-aware monitors, Probe **107** and Node **105** are therefore configured to scan the data portion of the packets and use pattern matching and other techniques to discern session-level and application-level data elements that might be critical to the metrics being collected.

[037] After parsing a packet, Node **105** and Probe **107** may classify the packet easily by the various protocols used. However, classification alone is not sufficient to assign the correct meaning to the data. In order to be able to assign the correct meaning to the data, the application that generated the traffic must be known. In other words, the application provides the critical context in which to interpret the data. By examining the TCP/IP port numbers, the application that generated the traffic may usually be identified.

[038] Before two application processes can communicate across a TCP/IP network, they must each indicate to the TCP process on their own host that they are ready to send and/or receive information. An application process that wants to initiate or accept connections must provide the TCP process with a port/socket number that is unique, at that time, on that host. To open a connection to an application process on a remote host, the local application process must know the remote application process's open port number.

Fortunately, most applications use a well-known port number, which is a generally agreed upon number (ports 0 – 1023 are managed by the Internet Assigned Numbers Authority, ports 1024 – 65535 are not officially managed but many ports are unofficially reserved for specific applications). Communication links are therefore described in terms of a source address and port paired with a destination address and port.

[039] To avoid tying up a well-known port with a single connection, one of the first things certain applications do after establishing a TCP connection to a well-known port is to establish a secondary port. This secondary port is a port not currently in use by any other connections or well-known services. Once the secondary port has been established, the connection is migrated to the secondary port. The original connection is then terminated, freeing the well-known port to accept additional connections.

[040] Therefore, for applications with well-known ports, it can be assumed that traffic to those ports is specific to the application associated with the port. Further, by observing the migration of well-known port connections to secondary ports, it may be determined that the traffic on the secondary ports also is specific to the application associated with the original well-known port. Still, the termination of secondary port connections must be observed to see if the host recycles the secondary port number and possibly assigns it to some other application.

[041] In some cases, a port is associated with more than one application. For example, a TELNET application may actually be a front-end for a number of hosted text-base applications. For example, a Citrix Metaframe sever may be hosting Peoplesoft and Microsoft Word. Without some ability to further parse and interpret the data, the actual application used may be obscured and incorrectly categorized. This additional interpretation of application identification is characterized by process identifiers, user identifiers, etc.

[042] As mentioned, Node **105** and Probe **107** can measure network traffic from both a flow and a conversation perspective. Flow related measurements associate recorded packet movement and utilization with time, while conversation measurements group flow related activities into "pairs" of bi-directional participation. Although some traffic is connectionless, each connection-oriented packet transmitted must be associated as part of some traffic flow (sometimes called connections, conversations, transactions, or sessions).

Indeed, for many transaction oriented applications, the time between the initial connection to the well-known port and the termination of the (secondary) connection represents the transaction duration and is the source of the primary metric referred to as application response time.

[043] To meter traffic flows (modeled as a conversation unit) Node **105** and Probe **107** must examine each packet to determine if it is the first packet in a new flow, a continuation packet in some existing flow, or a terminating packet. This determination may be made by examining the key identifying attributes of each packet (e.g. source and destination addresses and ports in TCP/IP) and matching them against a table of current flows. If a packet is not part of some existing flow, then a new flow entry may be added to the table. Once a packet is matched with a flow in the table, the packet's attributes may be included in the flow's aggregate attributes. For example, aggregate attributes may be used to keep track of how many bytes were in the flow, how many packets were in the flow, etc. If the packet is a terminating packet, the flow entry in the table is closed and the aggregate data is finalized. The flow's aggregate data might then be included in roll-up sets. For example, in the case of Probe **107** and Node **105**, the network administrator may be interested in per-flow and aggregate data per user per application.

[044] To allow association of traffic to a particular user, there must be some facility in place that captures user identification information so that it can be mapped to addresses used. For example, when "Betty Lou" logs into her workstation **104**, the workstation **104** will have an IP address assigned to it (which may change at some rate specified by the DHCP server, if one is used). User information and IP address may be captured so that traffic seen at other points in the network **106** can be mapped to "Betty Lou." In addition, traffic must be associated to a particular service level agreement ("SLA"). This is achieved by mapping user ID's (or groups) to service level definitions.

[045] To complicate correlation of end-to-end modeling of bi-directional conversation flows, network address translation (NAT) introduces the inability to resolve origination-to-destination target addressing. NAT hides or translates origination/destination node identifiers, such as IP addresses, along the conversation path. Before an end-to-end flow map can be constructed detailing point-to-point performance indicators, these addresses must be resolved and correlated. Several techniques may be used for overcoming

the problems associated with NAT. For example, artificial test packets may be injected into the network segment **106a** that can clearly be identified at each endpoint (for example, by forcing the packet to contain a particular pattern that is unlikely to occur normally in the network **106**). Another technique for overcoming problems associated with NAT is referred to as "conversation fingerprinting." Generally, conversation fingerprinting involves applying a patent-pending signature mapping formula to each conversation flow. Unlike all other methods and approaches requiring packet tagging or other invasive packet modifiers, conversation fingerprinting is non-intrusive and does not modify packets. Conversation fingerprinting enables the ability to "follow the worm" regardless of address translation; thus allowing performance measurements to be made and reported on an end to end basis. Methods for performing conversation fingerprinting are more fully described in the U.S. Provisional Patent Application entitled "Methods For Identifying Network Traffic Flows," filed on March 31, 2003, assigned Publication Number _____.

[046] Measurements regarding network traffic may be converted into metrics for some useful purpose, for example to validate the actual delivery of application quality of service ("QoS"). In accordance with certain embodiments of the present invention, a key performance indicator of QoS is the service level that is actually being delivered to the end-user. An application service level agreement ("SLA") is an agreement between a provider and a customer that defines acceptable performance levels and identifies particular metrics that measure those levels. The particular metrics and/or thresholds may be different for different combinations of applications and end-users.

[047] In addition, there are likely financial consequences for failure to meet the service guarantee specified in an SLA. Customers and providers both have a stake in verifying delivery of application services. Customers want to be sure they are getting what they paid for. When the Service Provider's quality-of-service failures impact the bottom line of the customers, customers will demand compensation (e.g., penalties). Providers that face penalties for noncompliance want to ensure they can prove the guaranteed quality of service is in fact being delivered. Customers and providers also face the additional problem of estimating the impact of new users and/or applications on their network(s). All of these issues involve identifying the metric (measurement to be made) and establishing thresholds for the metrics that define good and poor service levels.

[048] Probe **107** and Node **105** measure and provide visibility into multiple customer-defined metrics. In particular, Probe **107** and Node **105** are aware of extant service level agreements, their QoS definitions and thresholds that might impact the observed traffic. Probe **107** and Node **105** may be provided with functionality to direct the actions required when the metrics indicate a violation of the service guarantee.

[049] Traditional network analyzers provide several metrics related to network performance. While not necessarily complete, the following list represents network metrics: availability; network capacity; network throughput; link-level efficiency; transport-level efficiency; peak and average traffic rates; burstiness and source activity likelihood; burst duration; packet loss; latency (delay) and latency variation (jitter); bit error rates. These metrics are necessary, but not sufficient, to define metrics for application quality of service.

[050] For most applications, the critical metric is application response time, as perceived by the end user. Related metrics such as application throughput and node "think-times" are also critical metrics for defining application quality of service that are largely ignored by network-centric systems. In transactional systems, application response time may be defined as the time it takes for a user's request to be constructed, to travel across the network **106** to the application server **114**, to be processed by the application server, and for the response to travel back across the network **106** to the user's workstation. There are some variations on this definition, such as whether the time interval measurement should begin with the first or last packet of the user's request, whether the time interval measurement should end with the first or last packet of the server's response, etc. However, with the above basic definition in mind, a candidate metric can be defined.

[051] While application response time is probably the critical metric for determining end-user application quality of service, by itself it indicates very little about the quality of service. A more general metric, application responsiveness, must include information about the size of the request and the size of the response. If a transaction involves 100Mb of data, then a 1.5-minute response time is actually very good. The application responsiveness metric must also include areas of performance associated with node orientations.

[052] Application response time is meant to indicate the total delay between request and response. But this includes a number of independent factors, such as network delay, server delay and workstation delay. Network delay is the amount of time it takes to send the request and the response. This includes wire time (actually moving bits), network mediation and access times (collision detection and avoidance), network congestion back-off algorithms, routing overheads, protocol conversion (bridges), retransmission of dropped or broken packets. In general, everything involved in actually moving data. Note that by itself, this metric is generally not sufficient to validate an SLA. For example, it may be impossible for an ASP to know that the problem causing SLA breaches is not due to increased traffic on the customer's LAN.

[053] Server delay is the amount of time between when the server receives the request and the time it produces a response. An overloaded server may cause extended transaction delays as new requests are queued while previous requests are being processed. Also, certain transactions may require significant processing time even in the absence of other transactions loaded (e.g., a complex database query). Workstation delay may occur, for example, when a user initiates a transaction and then some other resource intensive process begins, such as an automated virus scan or disk defragmentation. Thus, the workstation itself may contribute to overall delay by taking longer than normal to produce acknowledgment packets, etc.

[054] By synchronizing and using a combination of the above-described metrics, performance problems and their locations may be identified and responsibility may be allocated. As an example, consider a typical case, where there is a workstation **104** on a customer LAN using the Internet to access an application server **114** on a provider's LAN. In this case, the provider is likely to avoid penalties if he can prove that responsiveness at his end is adequate. That is, once the request arrives at the edge of the provider's LAN, it is delivered and processed and the result is delivered back to the edge of the providers LAN within the performance thresholds. If the customer is experiencing an apparent Service Level breach, it could be as a result of the Internet, the customer's LAN or the user's workstation. Synchronized Probes **107** may be strategically placed at different points on the network **106**, such as at the edges of the customer's LAN and the provider's LAN, and

information from the Probes **107** may be correlated to isolate the offending network segment **106a** or device.

[055] As mentioned, Controller **109** may be configured to periodically transmit network traffic data to Diagnostic Server **111**. Diagnostic Server **111** represents the data management software blade that can be located in a centralized Performance Management Server **108** or in multiple Performance Management Servers **108**. The Performance Management Server(s) **108** can either be located at the customer site(s) under co-location arrangements or within a centralized remote monitoring center. The flexibility of the framework allows the management platform(s) to be located wherever the customer's needs are best suited. One physical instance of Diagnostic Server **111** can handle multiple customers. By way of example only, an Oracle 8i RDBMS for enterprise size infrastructures or MySQL for small/medium business (SMB) implementations may support the management platform; each providing a stable and robust foundation for the functionality of Modeler **113**, Trender **115** and Reporter **117**. Modeler **113**, Trender **115** and Reporter **117** all reside within the management platform of Diagnostic Server **111**.

[056] Diagnostic Server **111** receives data stream services from Controller at user-defined intervals. Diagnostic Server **111** stores that data for use by Modeler **113**, Trender **115**, and Reporter **117**. Modeler **113** produces data models (based on user-defined criteria) that automatically update to reflect changes in the currently modeled attribute as Diagnostic Server **111** receives each interval of data. This interface is ideal for the monitoring of extremely critical Quality of Service metrics and for personnel with targeted areas of concern requiring a near real-time presentation of data. The user interface for Modeler **113** may include data acquisition and presentation functionality. Data must be gathered from the user as to what models are to be constructed and with what characteristics. Data will then be presented to the user in a format that can be manipulated and viewed from a variety of perspectives. Once a model has been created and is active, Modeler **113** will request specific pieces of data from the Diagnostic Server **111** to update that model as the data arrives at predetermined intervals.

[057] Trender **115** utilizes traffic flows from Diagnostic Server **111** in order to provide a representation of the current network environment's characteristics. Once a 'baseline' of the current environment has been constructed, Trender **115** introduces

variables into that environment to predict the outcome of proposed situations and events. In particular, Trender **115** imports traffic flows from Diagnostic Server **111** in order to construct a 'canvas' of the operating environment. The amount of data imported into Trender **115** varies given the amount of data that represents a statistically sound sample for the analysis being performed. Once the data is imported, Trender **115** can then introduce a number of events into the current operating environment in order to simulate the outcome of proposed scenarios. The simulation capabilities of Trender **115** may be used to project the network architecture's behavioral trends into the future and provide predictive management capabilities. Thus, the outputs generated by Trender **115** may be used for capacity planning, trending, and 'what-if' analyses.

[058] Reporter **117** is a reporting engine (e.g., SQL-based) that communicates with Diagnostic Server **111** to request views of data based on any number of criteria input by its user. These requests can be made ad-hoc or as scheduled events to be initiated at customer defined intervals of time. The reports generated by Reporter **117** can be run (on demand or automatically scheduled) over any given interval or intervals of time for comprehensive views of aggregated quality of service performance. Support and management personnel can define views that follow their individual method of investigation and trouble-shooting. This flexibility lowers time to resolution by conforming the tool to their process rather than requiring them to change their process of analysis.

[059] In certain embodiments, the user interface for Reporter **117** may be configured as a Web-enabled portal, allowing for information capture from the user as well as display of the requested report. Although the report may be produced using another medium (i.e. HTTP, Microsoft Word, email, etc.) the user is able to view some representation of the report before the final product is produced. Individual users can select and construct personalized views and retain those views for on-going use. Reporter **117** may provide secured limited or defined view availability based upon user access as required by each customer. Personalization of user "portlets" enables the present invention to create virtual network operations centers (virtual NOCs) for each support and management personnel; thus supporting discrete JIT information directed toward the support effort.

[060] The interface from Reporter **117** to Diagnostic Server **111** may be based on Oracle's Portal Server framework and may leverage SQL commands executed upon the

database. Diagnostic Server **111** may return a view of the data based on the parameters of the SQL commands.

[061] Some of the measurements that are converted to metrics as described above are also functions of other measured performance characteristics. For example, the bandwidth, latency, and utilization of the network segments as well as computer processing time govern the response time of an application. The response time metric may be described as a service level metric whereas latency, utilization and processing delays may be classified as component metrics of the service level metric. Service level metrics have certain entity relationships with their component metrics that may be exploited to provide a predictive capability for service levels and performance.

[062] The present invention may include software modules for predicting expected service levels. Such modules may processes the many metrics collected by Node **105** and Probe **107** representing current conditions present in the Network **106** in order to predict future values of those metrics. Preferred methods for determining predicted values for performance metrics are discussed in more detail in U.S. Patent Application entitled "Forward-Looking Infrastructure Reprovisioning," filed on March 31, 2003, assigned Publication Number _____. Those skilled in the art will appreciate that any other suitable prediction methods may be used in conjunction with the present invention as well. Based on predicted service level information, actions may be taken to avoid violation of a service level agreement including, but not limited to deployment of network engineers, reprovisioning equipment, identifying rogue elements, etc.

[063] From a reading of the description above pertaining to various exemplary embodiments, many other modifications, features, embodiments and operating environments of the present invention will become evident to those of skill in the art. The features and aspects of the present invention have been described or depicted by way of example only and are therefore not intended to be interpreted as required or essential elements of the invention. It should be understood, therefore, that the foregoing relates only to certain exemplary embodiments of the invention, and that numerous changes and additions may be made thereto without departing from the spirit and scope of the invention as defined by any appended claims.

CLAIMS

What is claimed is:

1. A system for providing real-time, continuous end-to-end quality of service measurements and usage based metrics, in situ, in a distributed network environment comprising:

a node that meters network packets flowing through a workstation connected to a distributed network, the node configured to classify the network packets flowing through the workstation into workstation traffic flows and to generate aggregate node data comprising summarized attributes of the workstation traffic flows;

a probe that meters network packets flowing through a network segment of the distributed network, the probe configured to classify the network packets flowing through the network segment into network segment traffic flows and to generate aggregate probe data comprising summarized attributes of the network segment traffic flows at one or more layers of the protocol stack;

a controller connected to the distributed network and in communication with a database of service level criteria, the controller configured to receive the aggregate node data from the node and the aggregate probe data from the probe and to analyze the aggregate node data and the aggregate probe data to determine whether any of the service level criteria are breached; and

a diagnostic server connected to the distributed network and that receives data from the controller and performs monitoring functions based on the data.

2. The system of Claim 1, wherein the controller is further configured to command the probe to collect and transmit per-conversation probe data instead of aggregate probe data, in response to detecting a breach of any of the service level criteria based on the aggregate probe data.

3. The system of Claim 1, wherein the controller is further configured to command the node to collect and transmit per-conversation node data instead of aggregate node data, in response to detecting a breach of any of the service level criteria based on the aggregate node data.

4. The system of Claim 1, wherein the attributes of the workstation traffic flows and the attributes of the network segment traffic flows provide information about all seven layers in the OSI network model.

5. The system of Claim 1, wherein diagnostic server further performs trending, capacity planning and reporting functions based on the data.

6. A method for providing real-time, continuous end-to-end quality of service measurements and usage based metrics, in situ, in a distributed network environment comprising:

metering at a node network packets flowing through a workstation connected to a distributed network, and the node further classifying the network packets flowing through the workstation into workstation traffic flows and generating aggregate node data comprising summarized attributes of the workstation traffic flows;

metering at a probe network packets flowing through a network segment of the distributed network, the probe further classifying the network packets flowing through the network segment into network segment traffic flows and generating aggregate probe data comprising summarized attributes of the network segment traffic flows at one or more layers of the protocol stack;

receiving at a controller the aggregate node data from the node and the aggregate probe data from the probe and the controller analyzing the aggregate node data and the aggregate probe data to determine whether any of the service level criteria are breached, the controller being connected to the distributed network and in communication with a database of service level criteria; and

receiving at a diagnostic server connected to the distributed network data from the controller, the diagnostic server performing monitoring functions based on the data.

7. The method of Claim 6, further including the controller commanding the probe to collect and transmit per-conversation probe data instead of aggregate probe data, in response to detecting a breach of any of the service level criteria based on the aggregate probe data.

8. The method of Claim 6, further including the controller commanding the node to collect and transmit per-conversation node data instead of aggregate node data, in response to detecting a breach of any of the service level criteria based on the aggregate node data.

9. The method of Claim 6, wherein the attributes of the workstation traffic flows and the attributes of the network segment traffic flows provide information about all seven layers in the OSI network model.

10. The method of Claim 6, further performing trending, capacity planning and reporting functions based on the data by the diagnostic server.

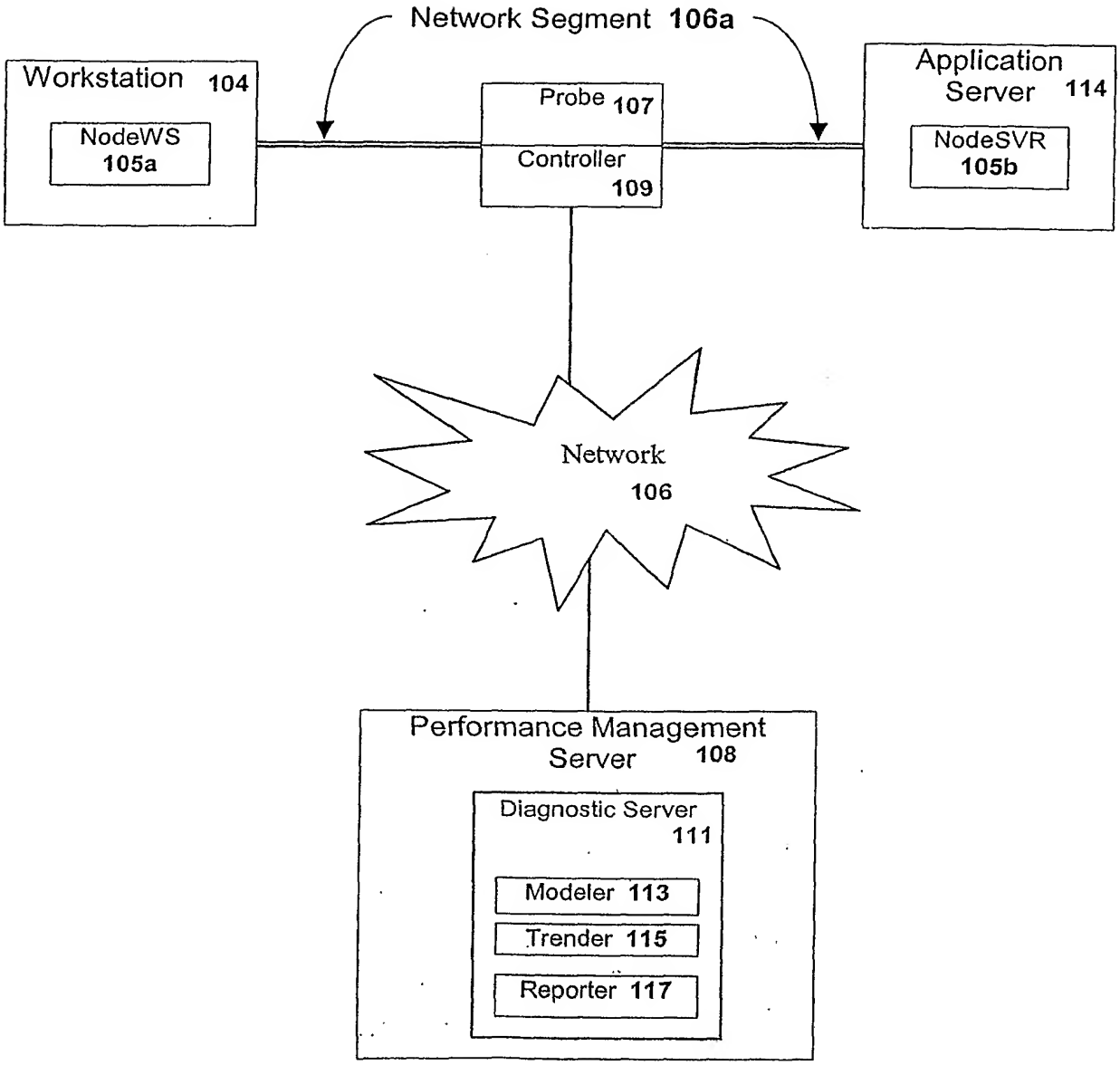
Network Segment 106a
Workstation 104
NodeWS 105a
Probe 107
Controller 109
Application Server 114
NodeSVR 105b
Network 106
Performance Management Server 108
Diagnostic Server 111
Modeler 113
Trender 115
Reporter 117

FIG. 1

INTERNATIONAL SEARCH REPORT

Internat[redacted] Application No
PCT/US 03/09855

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L12/24 H04L12/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 1 054 529 A (LUCENT TECHNOLOGIES INC) 22 November 2000 (2000-11-22) paragraph '0011! - paragraph '0016! paragraph '0018! paragraph '0022! - paragraph '0028! paragraph '0030! - paragraph '0034! paragraph '0050! - paragraph '0053!; figures 1-6 --- -/--	1-10

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 July 2003	04/08/2003

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INTERNATIONAL SEARCH REPORT

Internat[redacted] Application No
PCT/US 03/09855

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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